Costs of Road Infrastructure for Passenger and Freight Transport in The Netherlands

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Summary: In this paper the costs of construction, maintenance, operation and land use of road infrastructure in The Netherlands are allocated to several transport modes in passenger and freight transport. Opposed to earlier research, a considerable number of weight categories are distinguished for freight transport. The results show that costs per kilometre allocated to the heavier truck categories are considerably higher than those allocated to the lighter truck categories. De reason behind this is that on the basis of 4th power axle loads a large part of building and maintenance costs is allocated to the heaviest transport modes. Furthermore, large relative differences in average truck loading between the different weight categories have a substantial effect on the results. Concluding we can state that when the distinction between weight categories made in this study is ignored, a large part of the costs caused by heavy trucks is allocated to lighter trucks and passenger transport modes.

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1. Introduction

This paper is based on exploratory research and should be seen as a first step towards internalising the costs of road infrastructure for passenger and freight transport. It is a short and adapted version of a research report by the VU (2002) in assignment of the Ministry of Housing, Planning and the Environment. The assignment was to determine the magnitude of the costs of road infrastructure that can be allocated to passenger and freight transport.

Costs of road infrastructure are split up in construction costs, costs of land use, maintenance costs and operation costs. The main reason is that the method of allocating the costs to transport modes differs between these cost categories. In the calculations we distinguish between highways, motorways & provincial roads and municipal roads. Unique to this study is that a large number of truck weight categories is distinguished in order to analyse differences in cost estimates and compare the results to earlier studies that distinguish only a small number of categories. In line with European guideline 1999/62/EG we furthermore allocate costs to foreign trucks > 12 ton for the kilometres driven on Dutch highways.

The remainder of this paper looks as follows. The next Section discusses the data we use while Section 3 addresses the methods of allocating the costs to passenger and freight transport. The results are presented and discussed in Section 4. Section 5 contains the conclusions and suggestions for further research.

2. Costs of infrastructure, vehicle kilometres and axle damage factors

In this section we discuss the data we use for our research and the assumptions we had to make to get at the data format we need. In the following subsections we discuss subsequently the costs of infrastructure construction, maintenance, operation and land use, vehicle kilometres by transport modes distinguished in this study and the determination of axle damage factors.

2.1 Costs of construction, maintenance, operation and land use

CBS[2] Statistics distinguish construction, maintenance and operation costs of infrastructure of different types of road administrators, i.e. central, provincial and municipal government. In this study we make a distinction between highways, motorways & provincial roads, and municipal roads. Since both highways and motorways are under the central government's administration, we divide investment by the central government into investment in highways and investment in motorways on the basis of the historical development of the length of both road types. An assumption made here is that construction of highways is three times as expensive as construction of motorways (RSO, 2000).

Investments in infrastructure are classified according to road administrator for 1985 to 1999. We use a depreciation period of 35 years and a public interest rate of 4% per year. Since we calculate costs for the year 2000 we need an investment series from 1965 to 2000. Therefore, for the years 1965 to 1984, we use *total* investment in infrastructure got from CE (1999) and allocate it to the road administrators on the basis of their average share in total investment over the years 1985 to 1999. For the year 2000 we simply use the figure from 1999 because, in general, estimated investment deviates substantially from actual investment.

Infrastructure maintenance costs are also classified into costs of central, provincial and municipal government for the years 1985 to 1999 (CBS, Statline). For the year 2000 we use the aggregated maintenance costs in 1999 and add the average annual increase during the 1985-1999 period. We then allocate the costs to the different road administrators on the basis of their average share in total costs from 1985 to 1999. Furthermore, maintenance costs of roads in the central government administration are split into costs of highways and motorways on the basis of their relative land use (M^2) in the year 2000 (see VU, 2000). An identical procedure as for maintenance costs is used for operation costs, with the exception that the disaggregated series for operation costs is available from 1985 to 1991 only.

Costs of land use by infrastrcuture are calculated in the VU (2000) study. Costs of land use by roads, gas stations, rest and parking areas and landscape fragmentation *inside the urban area* are allocated fully to the municipal road network. On the basis of the VU (2000) study we can directly calculate costs of land use by highways, motorways &

provincial roads and municipal roads *outside the urban area*. Costs of land use by gas stations, refreshment areas and landscape fragmentation outside the urban area are allocated to the different road categories on the basis of their relative land use and length. Finally, costs of indirect land use associated with the transport of dangerous goods are allocated to freight transport only.

For allocation of costs of the municipal road network we use the method by TLN (2002). Since municipal roads have other functions besides a transport function, only part of municipal road costs can be allocated to motorised transport. The magnitude of this part is unknown for The Netherlands, which is why we set it at 70% following the Swiss Bundesamt für Statistik (see also TLN, 2002). Furthermore, TLN argues that 35% of this 70% can be attributed to parking areas and spaces. Since we do not take these costs into account we exclude these costs from our analysis. We allocate the remaining 65% of 70% of municipal road costs to motorised transport. A special feature of the methodology is that four municipal road categories are distinguished, with each category a specific distribution of vehicle kilometres by the distinguished transport modes.[3] For further details of allocation of municipal road costs see TLN (2002).

Table 1: Total costs of construction, maintenance, operation and land use of Dutch road infr a-structure divided into highways, motorways, provincial roads and municipal roads in 2000 (mi l-lion Euro)

	Highways	Motorways	Provincial roads	Municipal roads
Construction costs 89%	970.2	105.6	230.6	1906.8
Construction costs 11%	119.9	13.1	28.5	235.7
Maintenance costs Fixed	263.5	75.6	131.3	786.7
Maintenance costs Variable	112.9	32.4	56.3	337.2
Operation costs	161.0	51.3	-*	620.5
Costs of land use	48.9	72.2**		571.0
Costs of land use RDG***	0.5	0.2**		2.9

* No operation costs are known for provincial roads
** For costs of land use it was not possible to make a distinction between motorways and provincial roads
*** RDG means Routes for the transport of Dangerous Goods

Costs of infrastructure construction, maintenance, operation and land use for the distinguished road categories in 2000 are summarised in Table 1. Observe that costs of the municipal road network are highest in absolute terms for all distinguished cost types and that costs of land use are substantial compared to other fixed costs.

2.2 Vehicle kilometres of passenger and freight transport

Regarding passenger cars, motorbikes, busses, touring cars and delivery vans we got vehicle kilometres and other relevant data from CBS. The allocation of vehicle kilometres of above mentioned transport modes to highways, motorways & provincial roads, and municipal roads was done on the basis of data from CE (1999). Vehicle kilometres for passenger transport are summarised in Table 2.

Table 2: Vehicle kilometres of Dutch passenger transport (and delivery vans) on Dutch roads in 2000 in million km

	Total Vkm	Vkm on highways
Passenger car	98250	39300
Bus city/regional	393	12
Touring car	217	130
Motorcycle	1680	670
Moped	1715	-
Delivery van	16630	5820

Source: CBS, Statline

We use data from NEA (2001) on vehicle kilometres in 2000 of Dutch solo trucks < 12 ton and > 12 ton and on Dutch combination trucks >12 ton and trailers > 12 ton at both the entire Dutch road network and highways. The share driven at municipal roads is based on CE (1999) information. To allocate vehicle kilometres at the different road types to the many truck weight categories we distinguish in this study, we use CBS (1996) data. This is the most recent source that provides vehicle kilometres at the entire Dutch road network of many truck weight categories. We use the proportion of vehicle kilometres of each weight category in the total amount of vehicle kilometres in 1996 to further allocate truck kilometres driven in 2000 to the weight categories. Note here that we use these proportions regarding all distinguished road types.

Table 3: Vehicle kilometres of freight transport on Dutch roads in 2000 in million km*

	Total Vkm	Vkm on highways
*Dutch trucks**		
Truck solo <12t	554	277
Truck solo >12t	2495	1372
Truck combination >12t	1015	660
Tractor with trailer	3365	2187
*Foreign trucks**		
Truck (solo and combi) <12t	N.A.	43
Truck (solo, combi and tractor) >12t	N.A.	257

* Distinction of weight categories is done on the basis of the maximum permitted weight
Source: NEA (2001)

For vehicle kilometres driven by foreign trucks at Dutch *highways* we use data from NEA (2001) for trucks < 12 ton and > 12 ton. Allocation to the weight categories distinguished in this study was done on the basis of the data we used for Dutch trucks also (CBS, 1996). Table 3 summarises vehicle kilometres for freight transport at several road types in 2000. Table 4 provides (among other things) data on vehicle kilometres in 1996.

Table 4: Base data for freight transport

Truck solo							
Maximum Permitted Weight	Average Weight Unloaded	Average Weight Loaded[1]	Absolute Vkm in mln[1]	Relative Vkm[1]	% of vkm that was loaded[1]	Number of Axles	Axle Configuration
2.5 - 5.5	1.75	2.64	405	47%	75%	2	Single
5.5 - 9	3.25	5.21	177	21%	75%	2	Single
9 - 12	4	8.31	272	32%	75%	2	Single
			854	**100%**			
12 - 16	6	10.31	362	42%	75%	2	Single
16 - 22	6.5	15.64	319	37%	69%	3	Single
22 - 30	8.5	22.46	109	13%	62%	3 - 4	Single
30 - 35	11	30.11	42	5%	52%	4	Single
35 - 45	13	38.76	23	3%	52%	4 - 5	Single
45 - 50	17	45.29	8	1%	48%	5	Single
			863	**100%**			
Truck combination							
Maximum Permitted Weight	Average Weight Unloaded	Average Weight Loaded[1]	Absolute Vkm in mln	Relative Vkm	% of loaded Vkm	Number of Axles	Axle Configuration
12 - 16	5	8.20	12	2%	80%	3	Single
16 - 22	7	13.72	34	6%	76%	3	Single
22 - 33	11	17.54	49	9%	76%	3 - 4	Single
33 - 40	14	26.44	121	22%	74%	4	Single
40 - 45	16	31.55	161	29%	72%	4 - 5	Tan/Tridem
45 - 50	17	40.98	170	31%	64%	6	Tridem
			547	**100%**			
Tractor with trailer							
Maximum Permitted Weight	Average Weight Unloaded	Average Weight Loaded[1]	Absolute Vkm in mln	Relative Vkm	% of loaded Vkm	Number of Axles	Axle Configuration
12 - 16	6	9.03	4	0.3%	60.0%	3	Single
16 - 22	8	15.00	51	4%	75%	3	Single
22 - 32	11	21.50	106	8%	80%	4	Tandem
32 - 38	12.5	26.07	235	17%	76%	4	Tandem
38 - 45	13.5	29.55	511	38%	75%	5	Tridem
45 - 50	14.5	39.40	444	33%	67%	6	Tridem
			1351	**100%**			

[1] Data for 1996

Source: TLN, CBS (1996) and own calculations on the basis of TLN and CBS (1996) data

2.3 Axle damage factors

Data on average load of different truck weight categories are also got from CBS (1996). For average load per weight category in 2000 we simply use the data from 1996 because average load for 2000 could not be calculated from available data (at least not for all the weight categories we distinguish in this study). In the CBS study however, weight is defined as the 'maximum load' instead of the 'maximum allowed weight' definition that is used in underlying study. To transform the former into the latter, TLN provided data on average weight of empty trucks in diverse maximum load categories. For average load of foreign trucks on Dutch highways we also use the average loads from the CBS study for Dutch trucks. Note that, together with the assumption that the distribution of vehicle kilometres on Dutch highways among the weight categories is identical for Dutch and foreign trucks, this implies that foreign trucks at highways have the same costs per vehicle kilometre as Dutch trucks in the same weight category.

Important furthermore is that the tool to measure (relative) road damage of transport modes is based on axle damage factors. This implies that, next to average load, we require data on the average amount of axles and on axle configuration per weight category (see DWW, 2001, and VU, 2002, on how to account for axle configuration in calculating axle damage factors). These data were provided by TLN, where it should be noted that the number of axles per weight category is the legal minimum number of axles. Data for freight transport are summarised in Table 4.

3. Allocation method

This section addresses the methods we use to allocate costs of infrastructure to passenger and freight transport. Subsequently we discuss the method to allocate costs of construction, maintenance, operation and land use. *Costs of infrastructure construction* should be treated as fixed costs, at least the largest part of it. Based on a study by DHV (1992), and conform the allocation method in CE (1999) and TLN (2002), 89% of construction costs is allocated on the basis of vehicle kilometres and PCE (Passenger Car Equivalent). For the PCE's of different transport modes we adopt the method used by TLN (2002).[4] At a safety distance of 30 metres, which is required at a speed of 60 kilometres per hour, the PCE of a delivery van is equal to 1, that of a truck solo and a bus 1.2 and that of a truck combination and trailer 1.4. At a safety distance of 50 metres,

which is required at a speed of approximately 100 kilometres per hour, the PCE of a delivery van is equal to 1, that of a truck solo and a bus 1.1 and that of a truck combi and a trailer 1.2. However, TLN allocates 100% (of 89%) of construction costs at highways and motorways & provincial roads on the basis of PCE at 60 kilometres per hour. We argue that this is not realistic since the speed at these road types is at least 100 kilometres per hour most of the time. Therefore, we allocate 30% of 89% of construction costs on the basis of PCE at 60 kilometres per hour (30% is our estimation of the relative number of kilometres driven in peak hours). The remaining 70% we allocate on the basis of PCE at 100 kilometres per hour. At municipal roads the maximum speed is 50 kilometres per hour and accordingly we allocate 100% of 89% of municipal road construction costs on the basis of PCE at 60 kilometres per hour (which is close to 50 km\hour). Since construction costs are higher when a road has to be able to handle heavier vehicles, the remaining 11% of total construction costs is allocated on the basis of vehicle kilometres and 4^{th} power axle loads (DHV, 1992). Thus, this part of construction costs is variable in weight of the transport modes making use of the infrastructure and vehicle kilometres.

In DWW (2000), 70% of *maintenance costs* are regarded as independent of the intensity of use of the infrastructure and can therefore be regarded as fixed costs. Identical as allocation of fixed costs of construction, 30% of 70% of maintenance costs of highways and motorways & provincial roads is allocated on the basis of PCE at 60 kilometres per hour, while 70% (0f 70%) is allocated on the basis of PCE at 100 kilometres per hour. Fixed maintenance costs of municipal roads are again fully allocated on the basis of PCE at a speed of 60 kilometres per hour. The remaining 30% of road maintenance costs appears to be dependent on the intensity of use of the infrastructure and the weight of the vehicle. The DWW 2000) study suggest that only 2% of this 30% should be allocated on the basis of 2^{nd} power axle loads and 98% on the basis of 4^{th} power axle loads.

Operation costs consist largely of facilitating the road user, i.e. removing ice after frost, signposting, keeping clean rest and parking areas and the costs of police. As such, operation costs are largely fixed costs and they are therefore included in the results as average costs of infrastructure (a change in traffic volume will likely only induce a very small change in operation costs). Allocation of operation costs is done on the basis of vehicle kilometres only.

Table 5: Allocation methods of the different types of infrastructure costs

	Vkm	PCE 30 metres * Vkm	PCE 50 metres * Vkm	2nd power axle load * Vkm	4th power axle load * Vkm	Total
Construction costs						
Fixed costs (89%)						
HW[1] and MW & PR[2]	-	30%	70%	-	-	100%
MR[3]	-	100%	-	-	-	100%
Variable costs (11%)	-	-	-	-	100%	100%
Costs of maintenance						
Fixed costs (70%)						
HW and MW & PR	-	30%	70%	-	-	100%
MR	-	100%	-	-	-	100%
Variable costs (30%)	-	-	-	2%	98%	100%
Costs of land use						
HW and MW & PR	-	30%	70%	-	-	100%
MR	-	100%	-	-	-	100%
Operation costs	100%	-	-	-	-	100%

1. HW means highways
2. MW & PR means motorways & provincial roads
3. MR means municipal roads

In the VU (2000) study *costs of land use* by several types of infrastructure are calculated. Regarding direct land use, estimations on land use (M^2) were transformed into costs of land use (€\M^2) using information on costs of acquiring land with infrastructure construction as its specific destination. Indirect land use is associated with government imposed restrictions on the use of land adjoining infrastructure, usually for safety reasons or because of high noise levels.[5] Estimations of indirect land use are transformed into costs on the basis of opportunity costs, being the average value of land without restrictions minus the actual value of land. Costs of direct and indirect land use are allocated using the same procedure as is used for fixed construction costs. As mentioned before, costs of indirect land use associated with the transport of dangerous goods are allocated to freight transport only.

Table 6: Division of costs into fixed and variable costs

	Construction costs	Maintenance costs		Operation costs	Costs of land use
		Fixed	Variable		
Fixed costs	X	X		X	X
Variable costs			X		

In Table 5 a summary is given of absolute costs of construction, maintenance, operation and land use for different road categories, while Table 6 summarises which costs are presented as average and which are presented as variable costs of infrastructure in the

Section 4. Note that variable costs of construction are included as fixed costs per kilometre because they are dependent to a large extent on weight of the transport modes and only for a small part on vehicle kilometres.

4. Results

In this section the results are presented. As mentioned, a distinction is made between costs of highways, motorways & provincial roads and municipal roads. Our main interest is in the costs of freight transport. These are discussed in Section 4.2. For completeness, in the next section we present results for passenger transport (except for the delivery van).

4.1 Costs of passenger transport

Table 7 presents costs per kilometre for passenger transport at different road categories for the year 2000. Average costs at the entire Dutch road network are also presented.

Table 7: Costs of highway infrastructure, motorway & provincial road infrastructure, and m unicipal road infrastructure for Dutch passenger transport (in €ct per Vkm)[1]

	Construction costs 89%	Construction costs 11%	Maintenance costs	Operation costs	Costs of land use	Total Fixed Costs	Total Variable Costs
Highways							
Passenger car	1.89	0.00	0.51	0.32	0.10	2.81	0.00
Bus city/regional	2.13	1.92	0.58	0.32	0.11	5.05	1.80
Bus touring	2.13	2.74	0.58	0.32	0.11	5.87	2.58
Motorcycle	0.94	0.00	0.26	0.32	0.05	1.56	0.00
Delivery van	1.89	0.00	0.51	0.32	0.10	2.81	0.00
Motorways & provincial roads							
Passenger car	0.85	0.00	0.52	0.13	0.18	1.68	0.00
Bus city/regional	0.96	1.71	0.59	0.13	0.21	3.60	3.65
Bus touring	0.96	2.45	0.59	0.13	0.21	4.33	5.21
Motorcycle	0.42	0.00	0.26	0.13	0.09	0.91	0.00
Moped	0.42	0.00	0.26	0.13	0.09	0.91	0.00
Delivery van	0.85	0.00	0.52	0.13	0.18	1.68	0.00
Municipal roads							
Passenger car	2.53	0.11	1.04	0.78	1.66	6.13	0.21
Bus city/regional	0.59	2.02	0.23	0.78	0.39	4.00	2.88
Bus touring	0.44	1.63	0.17	0.78	0.29	3.31	2.32
Motorcycle	1.26	0.05	0.52	0.78	0.83	3.45	0.09
Moped	1.26	0.02	0.52	0.78	0.83	3.42	0.03
Delivery van	2.53	0.55	1.04	0.78	1.66	6.57	1.04

[1] For results on costs per kilometre at the entire Dutch road network, contact the authors

Striking is that costs per kilometre at municipal roads are substantially higher than costs at the two other road types. The reason for this is that total costs of municipal roads are substantially higher than total costs of the other two road types and that municipal roads are used less intensively than other roads.

Observe that for highways and motorways & provincial roads the fixed costs of construction, maintenance and land use are highest for busses because of their relatively large PCE's. In fact, differences in costs per kilometre between transport modes can be exactly traced back to differences in PCE's. Operation costs per kilometre are equal for all transport modes at identical road types because they these costs allocated on the basis of vehicle kilometres only. Furthermore, costs that are allocated using 4^{th} power axle loads, being variable costs of construction and maintenance, are allocated predominantly to busses and touring cars.

Table 8: Costs of Dutch highway infrastructure for Dutch freight transport (in €ct per Vkm)

	Construction costs 89%	Construction costs 11%	Maintenance costs	Operation costs	Costs of land use	Total Fixed Costs	Total Variable Costs
Truck solo < 12 ton							
2.5 – 5.5	2.13	0.00	0.58	0.32	0.12	3.15	0.00
5.5 – 9	2.13	0.04	0.58	0.32	0.12	3.18	0.04
9 – 12	2.13	0.24	0.58	0.32	0.12	3.39	0.24
Truck solo > 12 ton							
12 – 16	2.13	0.59	0.58	0.32	0.12	3.73	0.56
16 – 22	2.13	0.83	0.58	0.32	0.12	3.98	0.80
22 – 30	2.13	2.02	0.58	0.32	0.12	5.16	1.91
30 – 35	2.13	3.68	0.58	0.32	0.12	6.82	3.45
35 – 45	2.13	7.03	0.58	0.32	0.12	10.18	6.58
45 – 50	2.13	7.30	0.58	0.32	0.12	10.44	6.82
Truck combination > 12 ton							
12 – 16	2.38	0.07	0.65	0.32	0.13	3.54	0.08
16 – 22	2.38	0.55	0.65	0.32	0.13	4.02	0.53
22 – 33	2.38	0.94	0.65	0.32	0.13	4.41	0.90
33 – 40	2.38	3.14	0.65	0.32	0.13	6.61	2.96
40 – 45	2.38	4.81	0.65	0.32	0.13	8.28	4.50
45 – 50	2.38	4.85	0.65	0.32	0.13	8.31	4.54
Tractor with trailer > 12 ton							
12 – 16	2.38	0.09	0.65	0.32	0.13	3.56	0.09
16 – 22	2.38	0.77	0.65	0.32	0.13	4.24	0.74
22 – 32	2.38	1.49	0.65	0.32	0.13	4.96	1.42
32 – 38	2.38	3.05	0.65	0.32	0.13	6.52	2.87
38 – 45	2.38	2.65	0.65	0.32	0.13	6.11	2.49
45 – 50	2.38	4.25	0.65	0.32	0.13	7.72	3.99

For municipal roads the above mentioned results do not directly show in the results because allocation of municipal road costs is more complex than allocation for the other two road types (see Section 2 and TLN, 2002). Fixed costs of construction, maintenance, operation and land use for municipal roads are higher for passenger cars and delivery vans, but also for smaller trucks (see Section 4.2). Variable costs are still largely allocated to busses, but costs for delivery vans are also substantial at municipal roads.

4.2 Costs of freight transport

Our primary interest in this study is costs per kilometre of freight transport. Tables 8 to 10 present the results for highways, motorways & provincial roads and municipal roads respectively.

Table 9: Costs of Dutch motorway & provincial road infrastructure for Dutch freight transport (in €ct per Vkm)

	Construction costs 89%	Construction costs 11%	Maintenance costs	Operation costs	Costs of land use	Total Fixed Costs	Total Variable Costs
Truck solo < 12 ton							
2.5 – 5.5	0.96	0.00	0.59	0.13	0.21	1.90	0.01
5.5 – 9	0.96	0.03	0.59	0.13	0.21	1.93	0.08
9 – 12	0.96	0.22	0.59	0.13	0.21	2.11	0.48
Truck solo > 12 ton							
12 – 16	0.96	0.53	0.59	0.13	0.21	2.42	1.14
16 – 22	0.96	0.74	0.59	0.13	0.21	2.64	1.61
22 – 30	0.96	1.80	0.59	0.13	0.21	3.70	3.85
30 – 35	0.96	3.29	0.59	0.13	0.21	5.18	6.98
35 – 45	0.96	6.28	0.59	0.13	0.21	8.18	13.30
45 – 50	0.96	6.52	0.59	0.13	0.21	8.41	13.80
Truck combination > 12 ton							
12 – 16	1.07	0.07	0.66	0.13	0.24	2.16	0.16
16 – 22	1.07	0.49	0.66	0.13	0.24	2.59	1.07
22 – 33	1.07	0.84	0.66	0.13	0.24	2.94	1.82
33 – 40	1.07	2.81	0.66	0.13	0.24	4.90	5.98
40 – 45	1.07	4.30	0.66	0.13	0.24	6.39	9.11
45 – 50	1.07	4.33	0.66	0.13	0.24	6.42	9.18
Tractor with trailer > 12 ton							
12 – 16	1.07	0.08	0.66	0.13	0.24	2.18	0.18
16 – 22	1.07	0.69	0.66	0.13	0.24	2.79	1.49
22 – 32	1.07	1.33	0.66	0.13	0.24	3.43	2.86
32 – 38	1.07	2.72	0.66	0.13	0.24	4.82	5.79
38 – 45	1.07	2.36	0.66	0.13	0.24	4.46	5.03
45 – 50	1.07	3.80	0.66	0.13	0.24	5.90	8.07

As already mentioned costs for light trucks are relatively high at municipal roads. Costs for heavy trucks at municipal roads are low relative to costs for heavy trucks at other

roads. The reason for the latter is that heavy trucks make use of only a small part of the municipal road network and do not get allocated the costs associated with the part of the network they do not make use of.

Table 10: Costs of Dutch municipal road infrastructure for Dutch freight transport (in €ct per Vkm)

	Construc-tion costs 89%	Construc-tion costs 11%	Mainte-nance costs	Operation costs	Costs of land use	Total Fixed Costs	Total Variable Costs
Truck solo < 12 ton							
2.5 – 5.5	1.50	0.44	0.58	0.78	1.24	4.54	0.63
5.5 – 9	1.50	6.53	0.58	0.78	1.24	10.63	9.19
9 – 12	1.50	40.94	0.58	0.78	1.24	45.05	57.50
Truck solo > 12 ton							
12 – 16	0.59	0.62	0.23	0.78	0.63	2.85	0.89
16 – 22	0.59	0.88	0.23	0.78	0.63	3.11	1.26
22 – 30	0.59	2.13	0.23	0.78	0.63	4.36	3.04
30 – 35	0.59	3.88	0.23	0.78	0.63	6.11	5.51
35 – 45	0.59	7.43	0.23	0.78	0.63	9.66	10.51
45 – 50	0.59	7.70	0.23	0.78	0.63	9.93	10.90
Truck combination > 12 ton							
12 – 16	0.51	0.04	0.19	0.78	0.63	2.15	0.07
16 – 22	0.51	0.33	0.19	0.78	0.63	2.44	0.48
22 – 33	0.51	0.56	0.19	0.78	0.63	2.67	0.81
33 – 40	0.51	1.87	0.19	0.78	0.63	3.98	2.67
40 – 45	0.51	2.87	0.19	0.78	0.63	4.97	4.07
45 – 50	0.51	2.89	0.19	0.78	0.63	5.00	4.10
Tractor with trailer > 12 ton							
12 – 16	0.51	0.05	0.19	0.78	0.63	2.16	0.08
16 – 22	0.51	0.46	0.19	0.78	0.63	2.57	0.67
22 – 32	0.51	0.89	0.19	0.78	0.63	3.00	1.28
32 – 38	0.51	1.82	0.19	0.78	0.63	3.93	2.59
38 – 45	0.51	1.58	0.19	0.78	0.63	3.68	2.24
45 – 50	0.51	2.53	0.19	0.78	0.63	4.64	3.60

The main difference between underlying study and earlier studies on allocation of costs of infrastructure to transport (see CE, 1999, and TLN, 2002) is that this study distinguishes between a large number of weight categories within freight transport. The consequences are striking. Largely because of the 4^{th} power relation between axle load and road damage, in which axle configuration is also accounted for, costs per kilometre for heavier truck categories are substantially higher than costs for light(er) trucks. Especially costs for solo trucks from 35 to 45 and from 45 to 50 ton maximum weight are high. Relative to other heavy truck categories, costs for these two truck types appear to be high because of their high average loads and relatively few axles.

Furthermore, regarding fixed costs of construction, maintenance and land use of highways and motorways & provincial roads we can observe the same pattern as with passenger transport. That is, differences in costs per kilometre between transport modes can be traced back to differences in PCE, while differences in operation costs between transport modes at identical road types do not exist because these costs are allocated on the basis of vehicle kilometres only. Remember that, as mentioned in Section III, costs of foreign trucks on highways are identical to costs for domestic trucks on highways[6] because PCE, truckloads, truck weight and distribution of vehicle kilometres are assumed to be equal. Therefore, we do not present the costs for foreign trucks separately.

Regarding costs of municipal roads the above mentioned results hold but, identical to the results for passenger transport, the effects do not directly show in the results (see Table 10). As mentioned before, a consequence of the allocation method for municipal road costs is that light trucks, especially the truck solo 9-12 ton, get allocated extremely high costs per kilometre. This result raises the question whether he method of allocating municipal road costs is correct or needs (crucial) adaptations.

5. Conclusions and suggestions for further research

This study allocates costs of infrastructure construction, maintenance, operation and land use of highways, motorways & provincial roads and municipal roads to passenger and freight transport. Whereas earlier studies (see CE, 1999 and TLN, 2002) distinguish between trucks less and more than 12 ton only, this study discerns a multitude of truck weight categories. In general, the result show that differences in fixed costs (in €/km) can be traced back to differences in Passenger Car Equivalents. Furthermore, variable cost estimates for different transport modes show large variation. Since these costs are mainly allocated on the basis of 4^{th} power axle loads, heavy trucks get allocated substantially higher costs than light(er) trucks. We can therefore conclude that when few weight categories are distinguished, such as in CE (1999) and TLN (2002), a substantial amount of the costs caused by heavy trucks will be allocated to light trucks.

A few annotations and suggestions for further research are in order however. Note that the results are also influenced by differences in average loads between truck categories, based on data from 1996. The question is whether these data accurately represent actual

and contemporary differences in average truckloads. Furthermore, based on a study by DHV (1992), 89% of construction costs is allocated on the basis of PCE while 11% is allocated using 4th power axle loads. Since this study may not be up to date and does not distinguish between different road types, the calculations may have inaccuracies. Finally, the 4th power relation between road damage and variable construction costs is widely accepted and used. However, we know of no studies that distinguish as many weight categories as is done in underlying study. Precisely this distinction causes the large differences in cost estimates. Is the 4th power relation correct and when few weight categories are distinguished, light trucks get allocated costs that are (far) too high. It is also possible that when this many weight categories are distinguished, the 4th power relation breaks down especially for the heaviest truck categories. Since it is crucial for the magnitude of cost estimates, further research is required into the relation between road damage and axle loads.

Notes

[1] CE (1999), VU (2000) and TLN (2002) distinguish between trucks below and above 12 ton only.

[2] Statistics Netherlands (see http://www.cbs.nl).

[3] For instance, heavy trucks make relatively more use of main municipal roads than do light delivery vans that also make use of the smaller roads in a municipal road network.

[4] The TLN (2002) method accounts, next to size of a vehicle, for the time it takes for a vehicle to come to a full stop after hitting the breaks at different speeds. Since CE (1999) accounts for size of a vehicle only, which is plausible when allocating costs of parking areas and spaces, we prefer the method of TLN.

[5] Not included in this study, but worth mentioning, is that (costs of) indirect land use for ships are high because of free sight zones next alongside shipping routes, especially inside the urban area (VU, 2000).

[6] European guidelines state that trucks driving abroad need only pay costs of kilometres driven on highways in foreign countries.

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